Acropora in the U.S. Virgin Islands: A Wake or an Awakening? A Status Report Prepared for the National Oceanographic and Atmospheric Administration

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ABSTRACT

Many shallow reefs in the US Virgin Islands (USVI) had extensive stands of *Acropora palmata* (elkhorn coral) before white band disease and hurricanes caused dramatic declines in the late 1970s and 1980s. *Acropora cervicornis* (staghorn coral) abundance also was reduced by storms and disease. None of the reefs that has been surveyed recently in the USVI has higher coral of these species than it did 25-30 years ago. Although *A. palmata* colonies appear to be increasing in number and size on many reefs, colonies are usually isolated from each other and few sites have dense areas with high elkhorn coral cover. Sexual recruitment has been successful at some sites. Many colonies are in very shallow water making them especially vulnerable to storms and land-based development.

INTRODUCTION

In the 1960s and 1970s, *Acropora palmata* (elkhorn coral) was the main reef-building coral at depths of less than 10 m in the US Virgin Islands, growing in nearly monospecific stands on the reef crest and in the upper and lower forereef zones of well developed fringing and bank barrier reefs and on isolated patch reefs (Fig. 1). Although elkhorn coral was the most abundant coral in these areas at that time, its density varied greatly.

Figure 1. Elkhorn coral at Buck Island Reef National Monument, 1966.

Acropora cervicornis (staghorn coral) was also abundant, although not often found in dense thickets or well-defined zones. *Acropora prolifera*, actually a hybrid between the two other *Acropora* spp. (Vollmer and Palumbi 2002), was very rare[1].

In the USVI in the mid 1970s and 1980s, white band disease (WBD) and hurricanes caused dramatic declines in *A. palmata* (Gladfelter 1982, Rogers et al. 1982) and apparently in the other *Acropora* species as well. In 1961, President John Kennedy designated Buck Island Reef National Monument, St. Croix, in recognition of its remarkable elkhorn barrier reef. The significance of the coral reefs around St. John was specifically mentioned in the 1962 legislation that added the marine portions to Virgin Islands National Park (established in 1956).

The presence of these two units of the National Park Service (NPS) and Fairleigh Dickinson University's West Indies Laboratory on St. Croix led to some of the earliest research on the *Acropora* spp. and associated reefs, including studies of disease (Gladfelter 1982; Davis et al. 1986); hurricane damage (Rogers et al. 1982; Hubbard et al. 1991); physiology, calcification and growth rates (Gladfelter W. 1982; Gladfelter E. 1983a, b, c; 1984; Gladfelter and Gladfelter 1979; Gladfelter et al. 1978, 1989); nutrient budgets (Bythell 1988, 1990); productivity (Rogers and Salesky 1979; Adey et al. 1981), relationships with reef fish assemblages (Gladfelter and Gladfelter 1978), and spatial distribution (Anderson et al. 1986; Beets et al. 1986; Bythell et al. 1989; Hubbard 1989).

This report is a compilation of historical and recent information on *Acropora* spp. in the US Virgin Islands (St. Croix, St. John and St. Thomas) based on qualitative observations and quantitative studies investigating a variety of scientific questions and conducted with a number of different methods and approaches appropriate to the question being asked. It does not include all the research results of studies on *Acropora*, but rather focuses on studies that document patterns of abundance and distribution, and on some of the mechanisms thought to be responsible for the observed patterns.

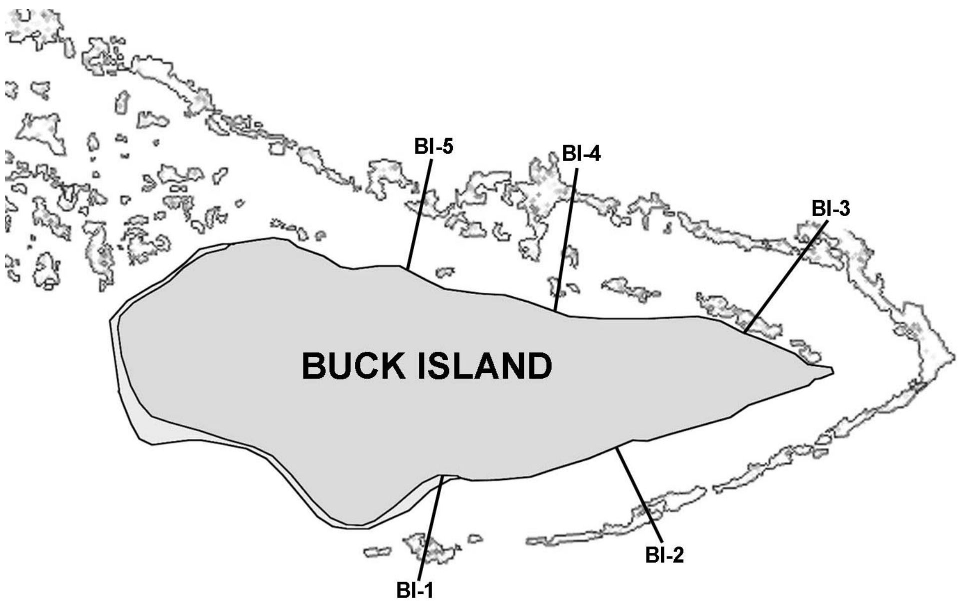
ST. CROIX

A substantial amount of information is available for *Acropora* spp. at Buck Island Reef National Monument (BIRNM), located 1.2 miles north of St. Croix. The most significant change to occur at BIRNM in the last three decades has been the demise of the *Acropora palmata* colonies that formed the shallow portions of the barrier reef. Bythell et al. (1989) summarized some of the major changes between 1976 and 1988, and their summary report on data from 1976, 1984 and 1988 is the basis for much of the following discussion (Gladfelter et al. 1977; Anderson et al. 1986). In 1976, five cross–reef transects were established at Buck Island, 3 on the north (BI-3, BI-4, BI-5) and 2 (BI-1, BI-2) on the south side (Fig. 2). At that time, the crest of the north and south bankbarrier reefs and the northern forereef was composed of greater than 50% live *A. palmata*.

Acropora palmata was the most abundant coral on the forereef slope down to the bank at a depth of 10-15 m in the north and east sections of the reef. In the south, this species was dominant to depths of 3-4 m. About 75% of the total live coral cover of 44% on the northern forereef slope was *A. palmata*. By 1984, when Anderson et al. (1986) surveyed the reef, the cover of *A. palmata* was dramatically reduced in the region of transect BI-3. In the forereef area, cover by hard corals was reduced to 20%, although *A. palmata* was still dominant (>10%). Anderson et al. (1986) reported patches of healthy elkhorn coral at this time with 80% live cover but also noted that most of the forereef had stands that were almost completely dead.

[1]Vollmer and Palumbi (2002) present data that demonstrate that *A. prolifera* is a morphologically variable, first generation hybrid of *A. palmata* and *A. cervicornis*.

Figure 2. Cross-reef transects established at Buck Island in 1976.

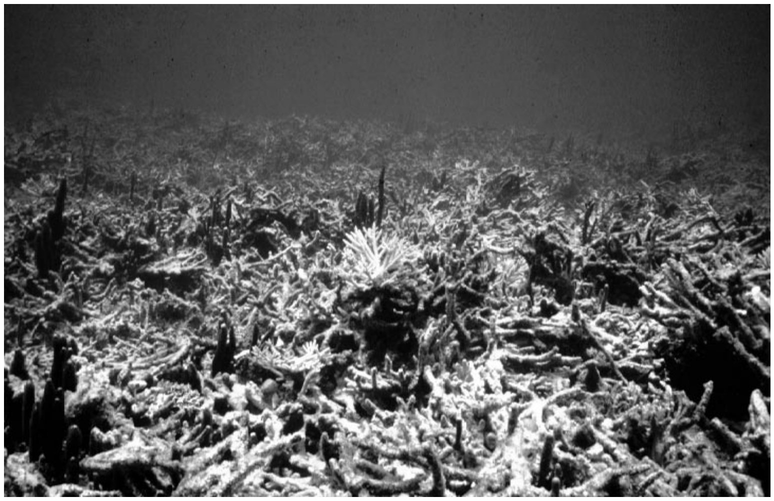


Surveys in the fall of 1988 confirmed many of the findings of Anderson et al. (1986), and showed additional declines in the *Acropora* spp. In 1988, live coral cover was less than 12% with only about 3% *A. palmata* on the forereef near transects BI-3 and BI-4. In contrast, along transect BI-5, *A. palmata* comprised 72% of the total cover of 27% on the upper forereef, suggesting that this area was less affected by the mass mortality which devastated most of the reef. This species was only rarely seen below a depth of 3-4 m on any part of the reef.

In 1976, *Acropora cervicornis* was noted in patches on the mixed coral/gorgonian bank seaward of the bank barrier reef and comprised 2% of the total coral cover of 27 %. Surveys in 1988 indicated virtual disappearance of this species on the north side of Buck Island and large reductions in abundance on the south side, although it comprised up to 2-3% of the coral cover in some localized areas off the southern reef (Bythell et al. 1989). *Acropora cervicornis* is now rare around St.Croix, at least in shallow water.

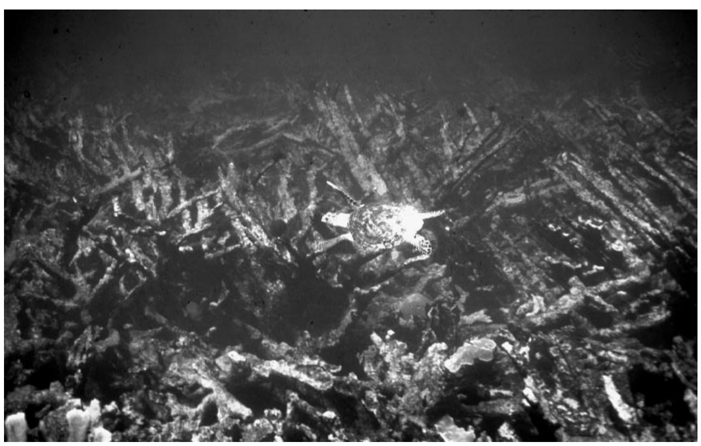
Acropora prolifera was not common around Buck Island in the 1970s, although in the lagoon off the east end of the island cover of this species reached about 60%. Bythell et al. (1989) suggested that this was perhaps the best-developed stand of this species on St. Croix. Anderson et al. (1985) noted thickets of mostly dead *A. prolifera* here in 1984. In fall 1988, cover of this species was less than 1% (Bythell et al. 1989) (Fig. 3).

Figure 3. Mostly dead thicket of *Acropora prolifera*, north backreef lagoon Buck Island, 1997.



The dramatic demise of the *Acropora* spp. at Buck Island in the 1970s and 1980s can largely be attributed to white-band disease (WBD) which affected many Caribbean reefs during this time period (Rogers 1985, Bythell and Sheppard 1993). The disease left extensive stands of these corals intact but dead (Fig. 4).

Figure 4. Intact dead *Acropora palmata* stand, east end Buck Island 1986.



White-Band Disease (WBD)

A 1973 report on Buck Island includes what is apparently the first reference to a condition later labeled "white band disease" by Dr. William Gladfelter. Photographs and a rough drawing show the distinctive narrow white band separating the living end of an elkhorn branch from the algal-encrusted dead base (Robinson 1973). In 1976, Gladfelter et al. (1977) found incidences of WBD at Buck Island but reported that only a few percent of the colonies in any area were affected. Impressive stands of living elkhorn were present at Buck Island at this time. Gladfelter began to measure the rate of progression of WBD on individual colonies and to monitor its effect on the populations of *A. palmata* on Buck Island and Tague

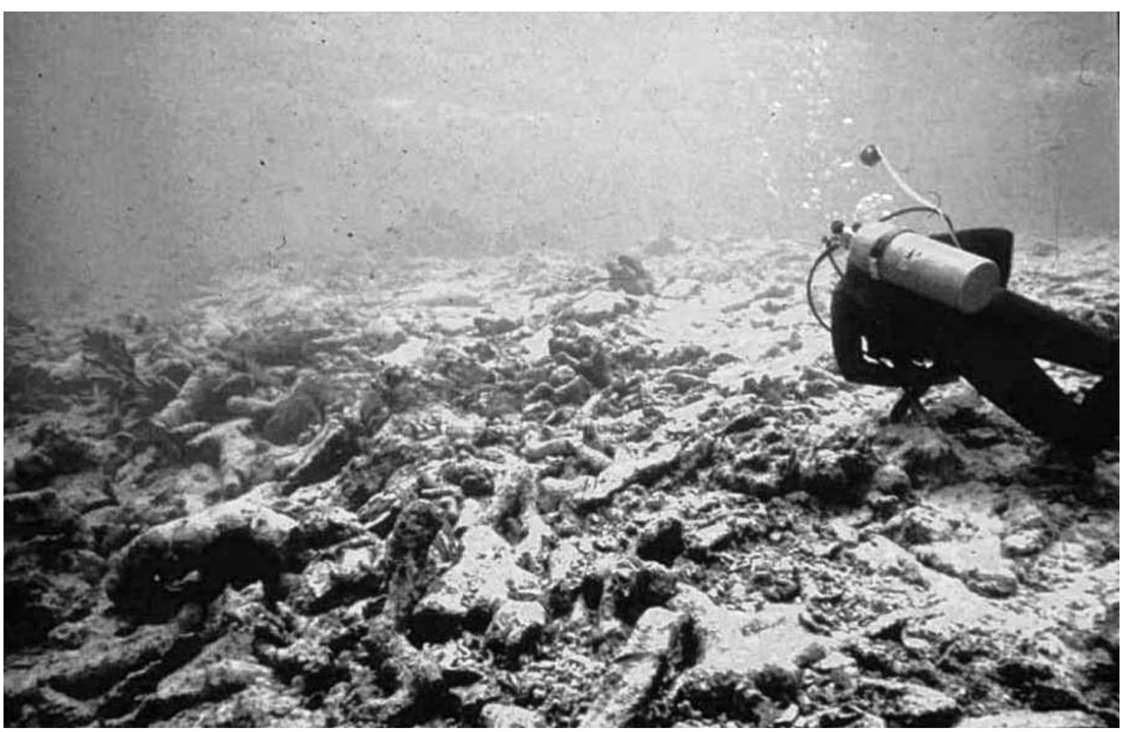
Bay Reefs (Gladfelter et al. 1977; Gladfelter 1982). The disease progressed at a rate of about 1 to 14 mm/day (with an average of c. 6 mm/day). Similarly, Davis et al. (1986) estimated a progression of 4-5 mm/day for the disease based on data from Buck Island.

Hurricanes

Hurricanes have also caused significant deterioration of coral reefs at Buck Island. In 1979, Hurricane David caused extensive physical damage to shallow elkhorn coral stands there (Rogers et al. 1982). Off the southeastern forereef, monitoring of storm-damaged elkhorn branches showed 66% of them were still alive11 months after the storm and many of these had begun healing and initiating new branches (Rogers et al. 1982). However, elkhorn coral recovery was hindered by white band disease which devastated this primary reef-builder (see above).

In 1989, Hurricane Hugo, an exceptionally powerful storm, caused further destruction (Fig. 5). The five cross-reef transects established in 1976 were re-surveyed (Gladfelter et al. 1991). The shallow forereef on the south side of Buck Island was reduced to pavement, and the coral rubble generated was transported up onto the reef crest, forming a raised berm 30 m landward of the crest (Hubbard et al. 1991). No *Acropora palmata* was recorded on the south reef in locations where it had previously been dominant. On the eastern shallow forereef *Acropora palmata* cover fell from 5% to 0.8% (Gladfelter et al. 1991) in an area that had once supported 85% cover of this species. The north reef at Buck Island was less severely damaged by Hurricane Hugo, but *Acropora palmata* populations were still reduced from approximately 1.8% to 1.0% cover on the forereef of transect BI-3, an area that had previously supported about 36% cover of this species (Gladfelter et al. 1991). These surveys clearly showed the effects of the storm, but most of the *Acropora* spp. mortality had already occurred. Interestingly, many of the *A. palmata* colonies killed by WBD remained upright, even in exposed areas like Buck Island Bar to the north.

Figure 5. Elkhorn coral fragments at Buck Island Reef National Monument after Hurricane Hugo (1989).



In 1988 more permanent monitoring sites were established at Buck Island (Bythell et al. 1992, 1993a). Although *Acropora* species were no longer a dominant part of the coral community at the start of this period, it can be seen that where they occurred there have been further reductions in cover over the past decade (Fig. 6), a period of unusually intense hurricane activity (Bythell et al. 2000a, b). One of the sites on the northern reef was established near cross-reef transect BI-5 (see above), and shows that hurricanes and disease have destroyed at least some of the stands that were still intact in 1988 (Bythell et al. 1989).

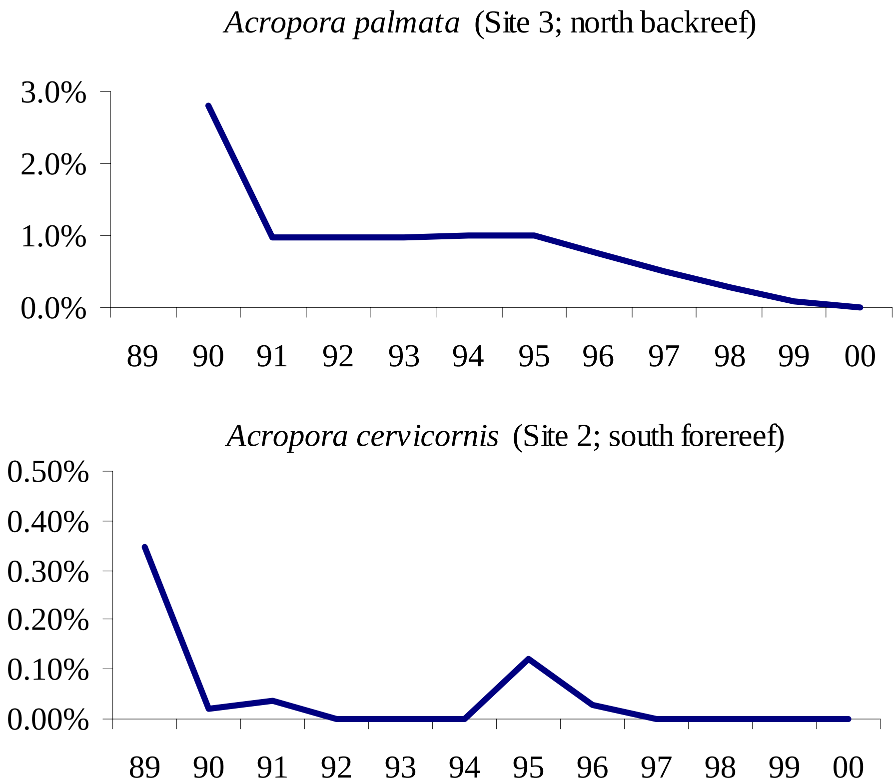


Figure 6. Reductions in cover of *Acropora palmata* and *A. cervicornis* on permanent transect monitoring sites at Buck Island over the past decade (Bythell et al. 2000a). No *Acropora* species were recorded on these transects in 2000.

Beginning in 1993, *Acropora palmata* colonies were observed in the southeast forereef in the area scraped clean by Hurricane Hugo, although they were only a minor component (0.4%) of the coral community recruiting to the area (Bythell et al. 1993a, 2000b). In 1995, after Hurricane Marilyn, some colonies were up to 1 to 2 m across but exhibited physical damage from the storm. Additional colonies have recruited to this area and appear to be in relatively good condition although they have been affected by subsequent storms and snail predation. West of Buck Island, numerous, large elkhorn colonies, some reaching 2 m across, can be found (Zandy Hillis-Starr, Brendalee Phillips, pers com.).

Recent monitoring of individual elkhorn colonies and surveys of spatial distribution

In January 2000, NPS biologists tagged colonies of *Acropora palmata* on the southeast forereef of Buck Island (less than 4 m deep). They have photographed them annually since then. All photographs are captured from video taken with a SONY DCR-VX700 Digital Handycam. Over this two year period, 14 colonies have grown noticeably or remained about the same in terms of total tissue cover, while 11 have lost live tissue (3 of these have died). Some of these colonies have exhibited very high rates of growth (as observed in photographs), apparently approaching the high end of the range reported previously at Buck Island (calculated as 4 to 11 cm/year in Gladfelter et al. 1978 and Rogers et al. 1982). *Coralliophila* snails were present on some colonies and actively feeding when examined in 2002 (One untagged colony in this area had 57 snails on it). Territorial damselfish were observed in photos of some colonies. Snorkel surveys conducted between February and August 2002 along the Buck Island forereef, both north and south, have shown an increase in the number of *Acropora palmata* colonies in water 1 – 10 m deep. The colonies range in size from several centimeters (sexual recruits) to large branching colonies over 2 m maximum dimension. Most sexual recruits have developed branches after settling on dead *A. palmata* structure, however there are also a number of "crusts" that are re-sheeting (reencrusting) dead *A. palmata* branches. Some of these crusts have spread into each other and have merged to cover, in one instance, an area over 5m long. In the backreef/lagoon entire *A. palmata* patch reefs that have been standing dead structure for years are now covered in living tissue. A rough visual estimate of the distribution of *A. palmata* colonies in the area of the 2000 *Acropora* tag site (south forereef) has recovered since Hurricane Hugo (1989) to maximum densities of 3 colonies per m^2. The majority of these colonies are smaller than 1 m. However, large colonies (>1 m) have increased in number as well, indicating survivorship of colonies first noted in 1993 and 1995 (Z. Hillis-Starr, pers. comm.).

In August-September 2002, the distribution of *A. palmata* colonies along Buck Island forereef was surveyed using a modification of the method developed by C. Rogers, B. Devine, and Christy Loomis (see below; Rogers et al. 2002). The colonies were divided into three size classes (small = 0-25 cm, medium = 26-100 cm, large >100 cm in maximum dimension), and their locations were recorded while snorkeling using handheld GPS units. To date an area of approximately 41,880 m^2 has been surveyed and 2,238 *A. palmata* colonies have been recorded (Fig. 7). Approximately 49 %, 35 %, and 16 % were in the small, medium, and large size classes, respectively (Fig. 8).

Other surveys of former elkhorn-dominated reefs around St. Croix and comparisons of past and present coral cover

In February, March and April 2002, W. Gladfelter surveyed selected reef zones around St. Croix that had been formerly dominated by *A. palmata*. Nine reef sites were surveyed in March 2002 to ascertain present cover and recent recruitment of *A. palmata*, and to compare current cover to cover during the 1970s-1990s. Three study sites were on the south shore (Robin Bay forereef; Isaacs Bay forereef; and Isaacs Bay backreef); three on the north shore (Tague Bay, Prtzl Reef; Tague Bay forereef, Romney Point; Channel Rock) and three off shore (eastern forereef Buck Island; Bythell's Reef; Friday Reef). At the eastern forereef of Buck Island, the study plot initiated in 1988 (Gladfelter 1991) was re-visited and the position and size (projected surface area, from photographs) of all live *A. palmata* colonies were recorded. At all sites percent cover (planar surface) of *A. palmata* was recorded. At some sites this was determined from measurements taken from photographic belt transects (Prtzl Reef, Romney Reef, Friday Reef, Buck Island forereef) while at other sites it was estimated from swimming several belt transects, approximately 50 m x 2 m, at a given site. At sites where photographic belt transects were made, size frequency distributions (made by measuring the maximum diameter of each colony) and colony density were also determined.

Figure 7. Distribution of *A. palmata* colonies around BIRNM eastern forereef, September 2002.

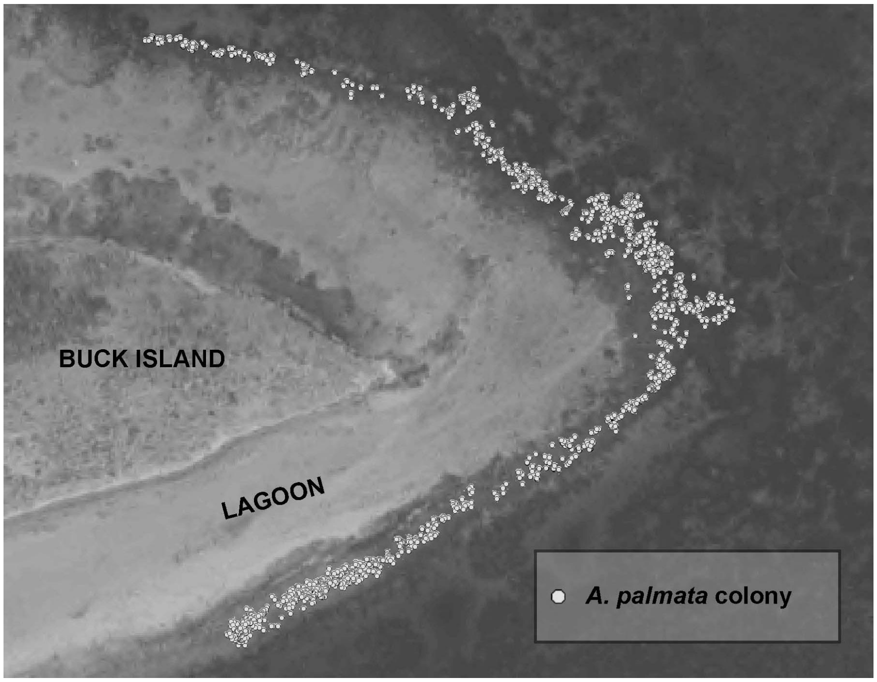


Figure 8. Distribution by size class of *A. palmata* colonies along the south forereef at BIRNM, September 2002.

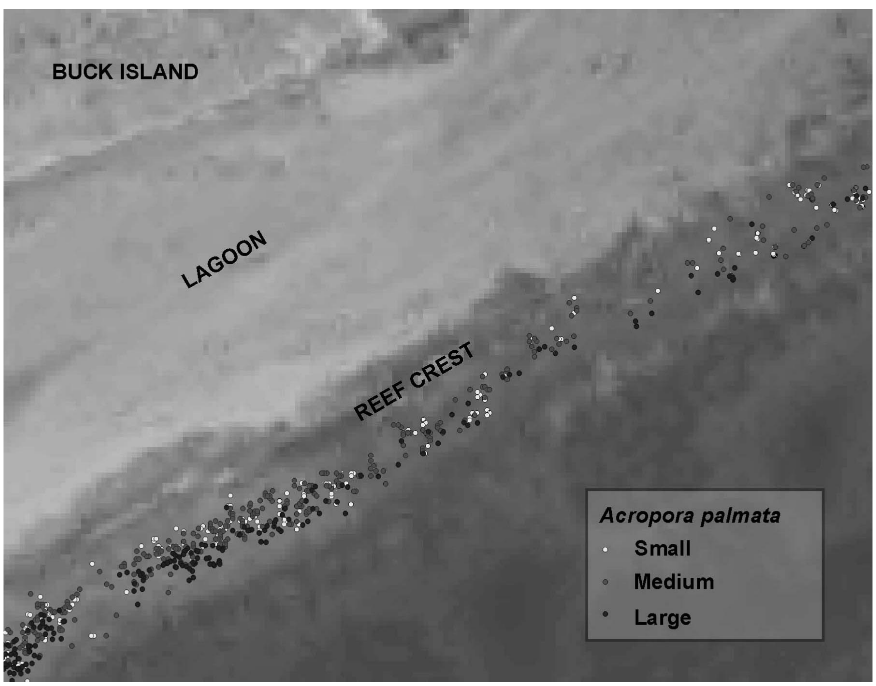


Table 1 compares past and present percent planar cover by *A. palmata*. Some of the previous values for cover were obtained from Adey et al. (1981) who used a chain transect method to determine cover of live tissue at several south shore sites (ranging from 10 to 66%) as well as vertical relief (1.9 to 3.0). Their data for cover were divided by their estimates for relief to arrive at a rough estimate of planar cover. Percent cover in the 1970s ranged from about 7-9% on the southern forereefs, to about 33% on the Isaac's backreef (estimated from Adey et al. 1981, and Gladfelter, pers. obs.). It was about 25-35% throughout much of the north shore and the offshore reef area (Gladfelter, pers. obs). Maximum documented cover was 62% on the eastern forereef of Buck Island (data calculated from 25 photoquadrats; Gladfelter et al. 1977), although in some relatively large areas the percent cover approached 100% (Fig. 9). Total live tissue cover was even higher, of course, as there were often several overlapping tiers of branches, covered on both sides. There was an average of 1.75 m^2 of live *A. palmata* tissue per m^2 of reef. The colonies in this forereef zone had extremely long branches oriented perpendicular to the approaching wave fronts (i.e. parallel to the direction of the prevailing waves). The largest colony measured (in 1988; Gladfelter, pers. obs.) had a length of 7.1 m.

Table 1. A comparison between the late-1970s and 2002 of percent planar surface cover of *Acropora palmata* at sites on St. Croix.

REEF NAME	mid-1970s % cover		2002 % cover
Southshore Reefs			
Robin fore reef		7%	<0.1%
Isaac fore reef		9%	<0.1%
Isaac back reef		33%	0.5-1.0%
Offshore Reefs			
Channel Rock	estimated	35%	0.1-0.5%
Friday Reef	estimated	35%	2.4%
Bythell's Reef	estimated	35%	0.5%
BI Barrier Eastern fore reef		62%	0.5-1.0%
Northshore Reefs			
Tague Bay FR (Romney)		47%	3.6%
Tague Bay (Prtzl Reef)	estimated	25%	1.4%

At present (2002), no reefs can be considered *A. palmata*-dominated as they were in the 1970s, yet all the surveyed sites show some live *A. palmata*, and some show evidence of at least two successful recruitment events in the past 10-15 years. Cover on the south forereefs is <0.1%. At the other sites, the cover ranges from 0.1 to 3.6%. Total live coral tissue reduction has been much greater than it may at first appear. For instance, in 1977, the percent cover in the Romney Point area was measured as 47% (Gladfelter 1982). It is now 3.6%, 7% of the late 1970s level. Yet the total surface area of live tissue is actually much less because the present colonies are small, and many are primarily crusts, rather than complex three-dimensional colonies. Previously, many colonies stood several meters above the substrate with live tissue covering not only the top and bottom of the branches, but also extending down to the base of the colony as well. Thus overall tissue reduction in the reef zones formally dominated by *Acropora palmata* is almost catastrophic, two orders of magnitude or greater.

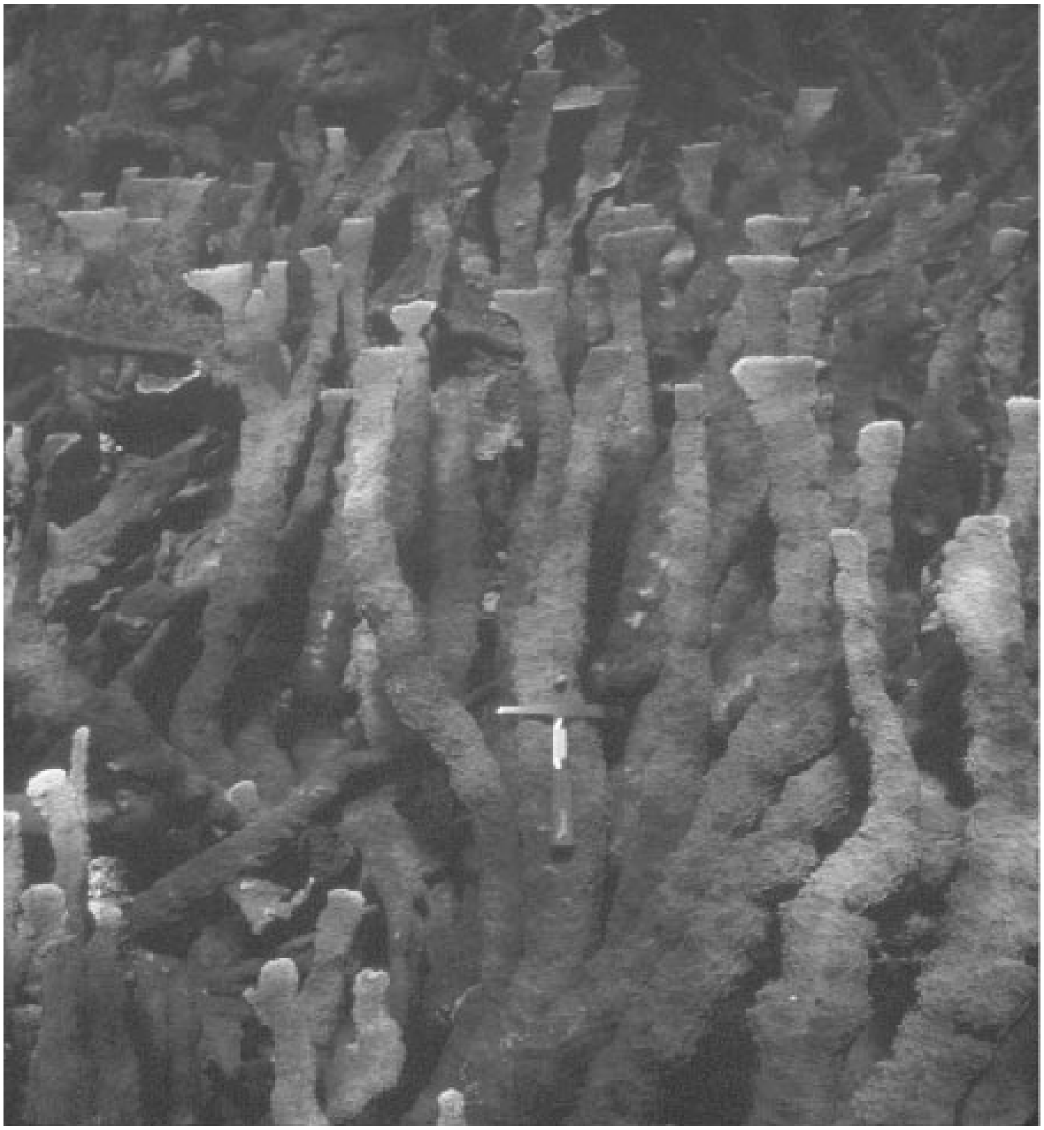


Figure 9. *Acropora palmata* colonies on the eastern forereef of Buck Island in 1977.

On the eastern forereef of Buck Island (in the 200 m^2 study plot; Table 2) there was a drastic reduction in total number of colonies from 1988 (106 colonies) to 2002 (10 colonies), and a reduction in total % planar cover, from 5% to 1%. In 1989, the site was re-surveyed the weekend before Hurricane Hugo arrived. There were 104 colonies of which 98 remained from the 106 recorded in 1988 and six new ones (presumably 8 were lost to WBD). In a 1990 survey several months after Hurricane Hugo, only 17 colonies were clearly recognizable as pre-Hugo, and many of these had been displaced and/or had a reduction in surface area; there were 33 colonies in the plot with a total planar cover of 0.8%. In 1991, there were 61 colonies in the plot, over half of which were small, recent recruits. After Hurricane Marilyn hit St. Croix in 1995, the plot was again surveyed, and only 33 colonies remained, of which only 7 were from the pre-Hugopopulation. Two other hurricanes, Georges (1998) and Lenny (1999) also hit St. Croix. In 2002, only 4 of the pre-Hugo colonies remained, although each had grown. The results of this study have some interesting implications for the genetic composition of any new population that may develop at this site. Only a very few, rather small colonies of the pre-Hugo population have survived. It would take years before they could repopulate this site asexually. Even though the recruits from the 1990-1991 recruitment event appear to have died at this site, it apparently is an area capable of successful recruitment. A new population established at this site may well have a very different genetic make-up from the original population, as it will be primarily composed of sexual recruits (which may then grow, fragment, and expand their zone). On three sites, Prtzl Reef, Romney Reef, and Friday Reef, some parameters of population structure, size frequency and density data, were determined. Recruitment of *Acropora palmata* was first noticed in 1992 on Prtzl Reef, when many colonies of approximately 10-15 cm in height were observed (Gladfelter, pers. obs.). In 2002, this reef had many circular colonies, varying in size from new recruits (less than 10 cm in diameter) to colonies as large as 120 cm in diameter. As this site is only about 0.5 m to 1.0 m deep, it has been directly impacted by the many storms that have affected St. Croix in the past decade. Some of the colonies had obviously been overturned, but had re-cemented to the substrate and new branches were growing outwards and upwards. The Romney Point section of Tague Bay forereef had the most abundant *A. palmata* in the entire forereef zone (about 2 m depth). At its richest area, coral cover was 3.6%, the highest measured anywhere during this study. The colonies ranged from small crusts to large colonies almost 2 m in diameter. While there was some evidence of small colonies resulting from successful sexual recruitment, many of the colonies appeared to be the results of fragmentation and re-cementation. At Friday Reef, at a depth of 4.5 m, the colonies were circular, and all appeared to have been the result of successful sexual recruitment. Coral colonies measured from the photoquadrats ranged from small colonies up to 150 cm in diameter, with many around 80 cm. At both Prtzl Reef and Friday Reef, the present populations may be entirely derived from successful sexual recruitment. One recruitment episode may have been in 1990 (as at Buck Island) and another about a decade later.

Table 2. Fate of *Acropora palmata* colonies on Study Plot #1 (20 m x 10 m) on the eastern forereef of Buck Island, including percent planar surface cover, colony density and number (no.) of remaining pre-Hugo colonies.

YEAR	% cover	No. colonies/200m^2	No. pre-Hugo	NOTES
1977	62%			
1988	5%	106		
1989		104	98	8 lost to WBD/6 added
	HUGO			
1990	0.8%	33	17	displaced
1991		61		1990 recruitment
	MARILYN			
1996		33	7	Marilyn mortality?
	LENNY			
2002	1%	10	3	Lenny mortality?

Conclusions for St. Croix

• Populations of *A. palmata* which dominated reefs on the eastern half of St. Croix (with ca. 10% up to almost 100% planar cover, covering a total area of almost 10 km^2) in the late 1970s have been reduced to < 0.1% cover in many areas to a maximum of 3.6% by 2002.
• Several sites (on the order of hundreds of m^2) have numerous young, healthy *A. palmata* colonies, many of which are the result of more than one successful episode of sexual recruitment.
• Barring devastation by storms (for which the species has shown remarkable adaptations for survival), disease (WBD was very rarely observed in this current survey), or predators these populations appear capable of recovery in the future.
• Over half of the individual colonies of elkhorn coral that have been monitored since January 2000 at Buck Island have grown, some of them substantially, although some colonies have died.
• Recent surveys to determine the presence and distribution of *A. palmata* along Buck Island's barrier reef show dramatic signs of recovery of the species. Although there was a very patchy distribution of colonies, in the densest areas there was a maximum of 3 colonies per m^2 .

ST. JOHN

Reefs off St. John once dominated by *Acropora palmata* have been affected greatly by white band disease and hurricanes.

White-Band Disease

During surveys in early 1984, Beets et al. (1986) found WBD at seven sites off the northern shore of St. John, although it was not common at any location. At the time of their work, some stands of live elkhorn were still present on many of the reefs, but other areas had piles of storm-generated rubble and standing dead colonies probably killed by WBD. The most impressive stand of living elkhorn was found along the western shore of Haulover Bay off the island's north shore. This and other shallow reef areas are now graveyards of dead elkhorn coral, with branches and fragments interspersed among algal covered skeletons still in normal growth position.

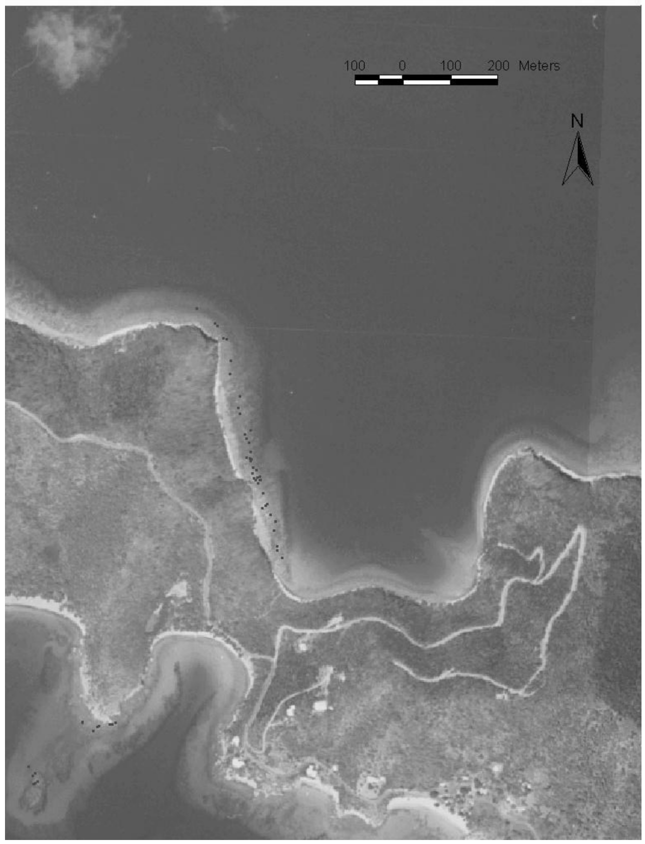
Hurricanes

Hurricanes David (1979) and Hugo (1989) caused severe destruction on the reefs of St. John. In Fish Bay and Reef Bay, powerful waves from Hurricane David smashed elkhorn colonies and deposited the fragments in ramparts on top of the reef crests (Beets et al. 1986). Even in the absence of major storms or other obvious stresses, shallow elkhorn reefs are particularly vulnerable. For example, 40 of the 50 elkhorn corals that were monitored over a seven month period in 1987 in Hawksnest Bay, St. John exhibited algal growth, tissue loss from corallivorous snails and other unknown predators, bleaching, and physical breakage (probably from boats and northern swells) (Rogers et al. 1988).

Recent surveys of *Acropora* spp. in St. John

Biologists and GIS-specialists from the US Geological Survey, National Park Service and the University of the Virgin Islands (and volunteers) are collaborating on surveys of *Acropora* spp. around the USVI (primarily around St. John and St. Thomas). They have developed a protocol for mapping and assessing the condition of elkhorn colonies based on recording GPS waypoints for each surveyed colony along with data on depth, size (estimated from 3 measurements), presence of disease and predators, percent dead, etc. Photographs are also taken of each colony, and all data are entered into a database. The GPS waypoints are mapped onto geo-referenced aerial photographs providing information on spatial patterns (see Figure 10; Rogers et al. 2002). Over time, they hope to be able to document if there is an increase in both the number and size of the elkhorn colonies. The protocol is more difficult to use when colonies are in dense stands (although such stands are now found at only 2 sites around St. John). However, the GPS unit can be used to delineate a polygon around the stand, and at least some of the desired data can be collected. Recent work to date around St. John has focused on elkhorn, although the same protocol is being used to survey *A. cervicornis* (staghorn).

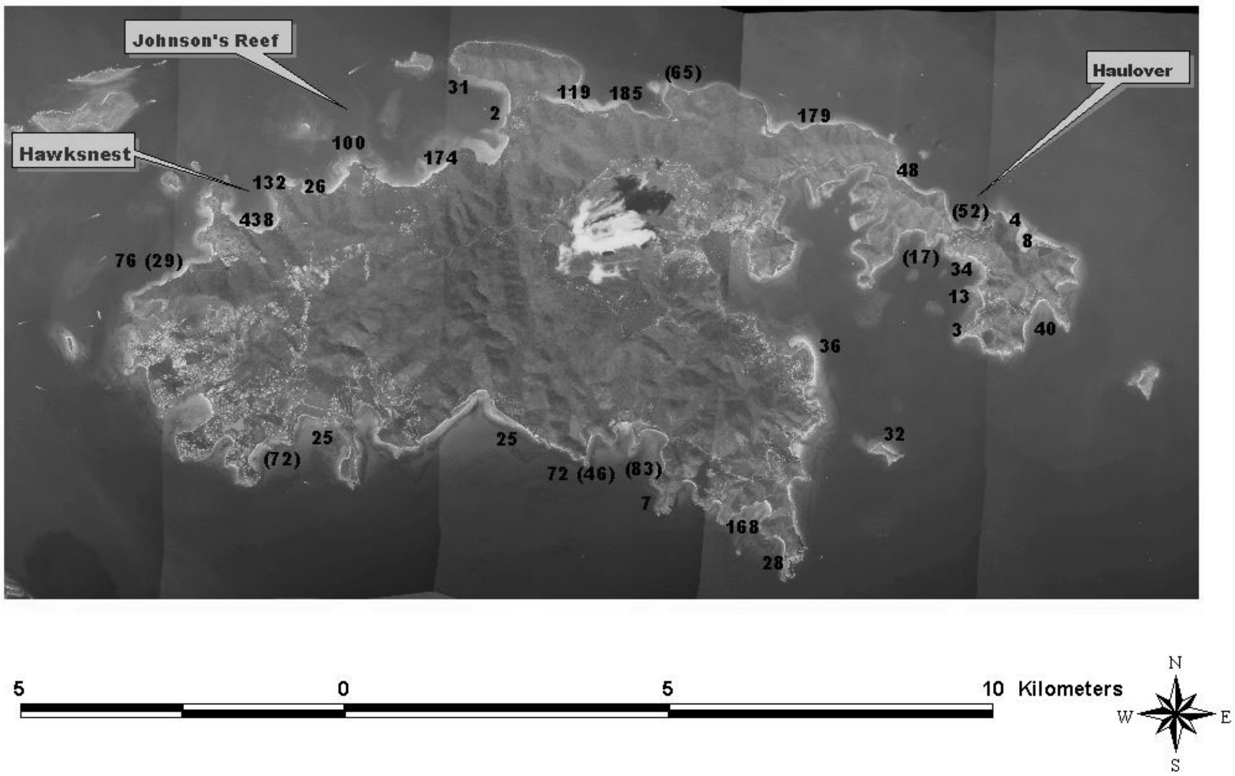
Figure 10. Aerial photograph of Haulover Bay with GPS waypoints indicating elkhorn locations in the western portion of the bay.



Surveys have been done around most of the island of St. John. Figure 11 reflects data collected from four different visual census methods and sources; the detailed method where GPS coordinates and data on colony condition are collected on individual colonies and three similar rapid assessment methods that collect limited data on colony size distribution and abundance. Values in Figure 11 reflect the total number of individual, discrete colonies along each section of coastline, combining data from all methods. Colonies range in size from several centimeters to 200 centimeters in greatest dimension. Numbers in parentheses indicate the abundance of colonies with detailed information. The other numbers refer to totals of individual colonies collected using rapid assessment methods. In some cases, colonies are aggregated and in other cases, colonies are scattered along a stretch of shoreline. Abundances are underestimates since many areas have not been sampled yet. Data were collected from May 2001-August 2002.

Preliminary analysis of data on 279 elkhorn colonies from 5 locations around St. John shows that many of the corals are relatively small (Fig. 12) and could have become established since Hurricane Hugo (1989) and Hurricane Marilyn (1995). New sexual recruits have definitely become established on reefs formerly dominated by elkhorn coral. Coral-eating snails were present on about 12% of the colonies surveyed. About 25% of the colonies were partially dead (1 to 85%). No active white-band disease was seen.

Figure 11. Distribution of elkhorn colonies around St. John.



These surveys of elkhorn coral around St. John show very patchy distribution, with Hawksnest Bay and Johnson's Reef having the highest amount of this species. At Hawksnest Bay, over 300 elkhorn colonies are growing on one patch reef. The elkhorn coral in this bay declined in the late 1980's and early 1990's presumably from a combination of white band disease and storm damage, although no quantitative data are available. A patch reef in the eastern part of this bay has very few living elkhorn colonies. Runoff following 18 inches of rain in a 24 hour period in April 1983 is most likely responsible for killing at least some of the coral in this portion of the bay (E. Gibney, pers. comm.) (Construction in this watershed had resulted in deposition of large amounts of sediment at the head of the gut that empties into eastern Hawksnest).
In 1999, numerous colonies of *A. palmata* were observed growing in western Hawksnest Bay. Hurricane Lenny in November 1999 and a January 2000 storm with extremely large swells destroyed some of these, although most colonies remain intact. In February 2000, 149 live colonies and 51 living fragments of elkhorn were recorded within an area of $100m^2$ on one patch reef (Rogers 2000). The cover of live elkhorn in this small reef area was about 30%. The reef continues to be susceptible to runoff from the developed watershed above the bay. Storms, disease, predators and damage from boats continue to cause elkhorn colony mortality around St. John. In April 2002, an 85' ferry grounded on Johnson's Reef inside Virgin Islands National Park, causing extensive damage to living elkhorn colonies. Two other boats have hit this reef since then.

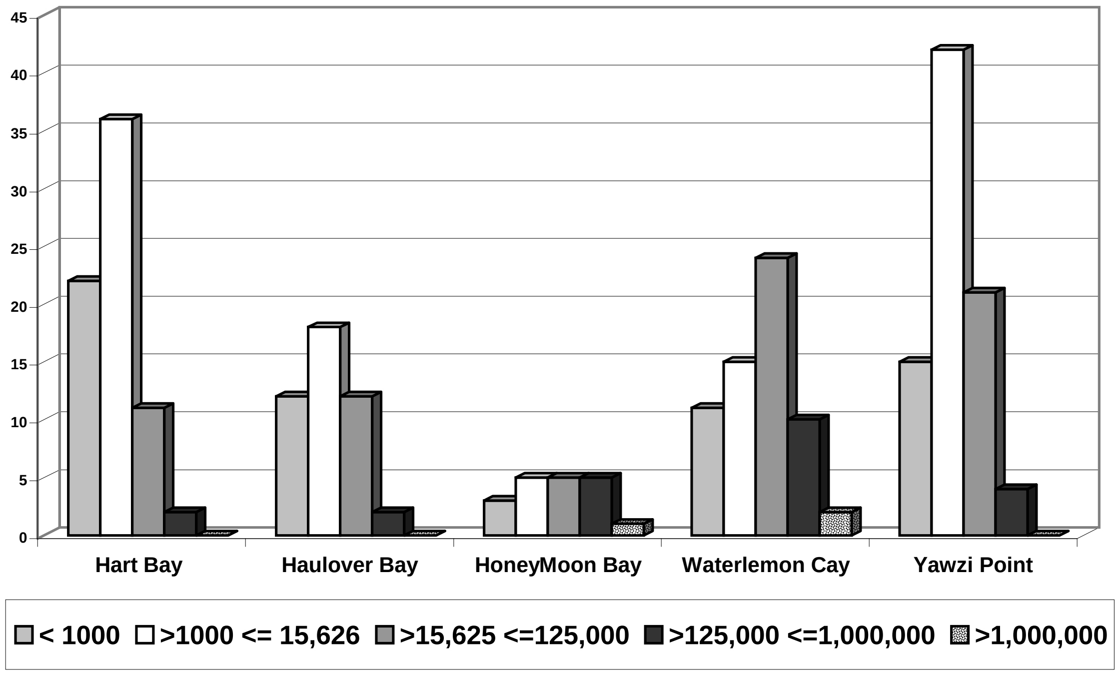


Figure 12. Size distribution of elkhorn colonies around St. John. Units are cm^3 (from multiplication of height, length and width measurements).

Acropora cervicornis

No detailed surveys of *Acropora cervicornis* have been done around St. John, but general observations document widespread, mostly isolated colonies in depths of at least 8m. No deeper surveys have been done specifically to quantify the abundance of this species around the island. No extensive "thickets" of this species are present, except in Saba Bay, off the east end of St. John. Hansen Bay, on the east end of St. John, has a high density of mostly isolated colonies (over 112 colonies in an area of about 6,950 m^2 on one patch reef (Rogers 2000). The cover of live elkhorn in this small reef area was about 30%. The reef continues to be susceptible to runoff from the developed watershed above the bay. Storms, disease, predators and damage from boats continue to cause elkhorn colony mortality around St. John. In April 2002, an 85' ferry grounded on Johnson's Reef inside Virgin Islands National Park, causing extensive damage to living elkhorn colonies. Two other boats have hit this reef since then). Damselfish territories and possibly white-band disease are frequently noted on staghorn corals.

Acropora prolifera

A single dense stand of this "species" has been videotaped in Saba Bay. There is no development in this watershed, but it is now for sale and any development of the steep upland areas will threaten survival of these shallow colonies.

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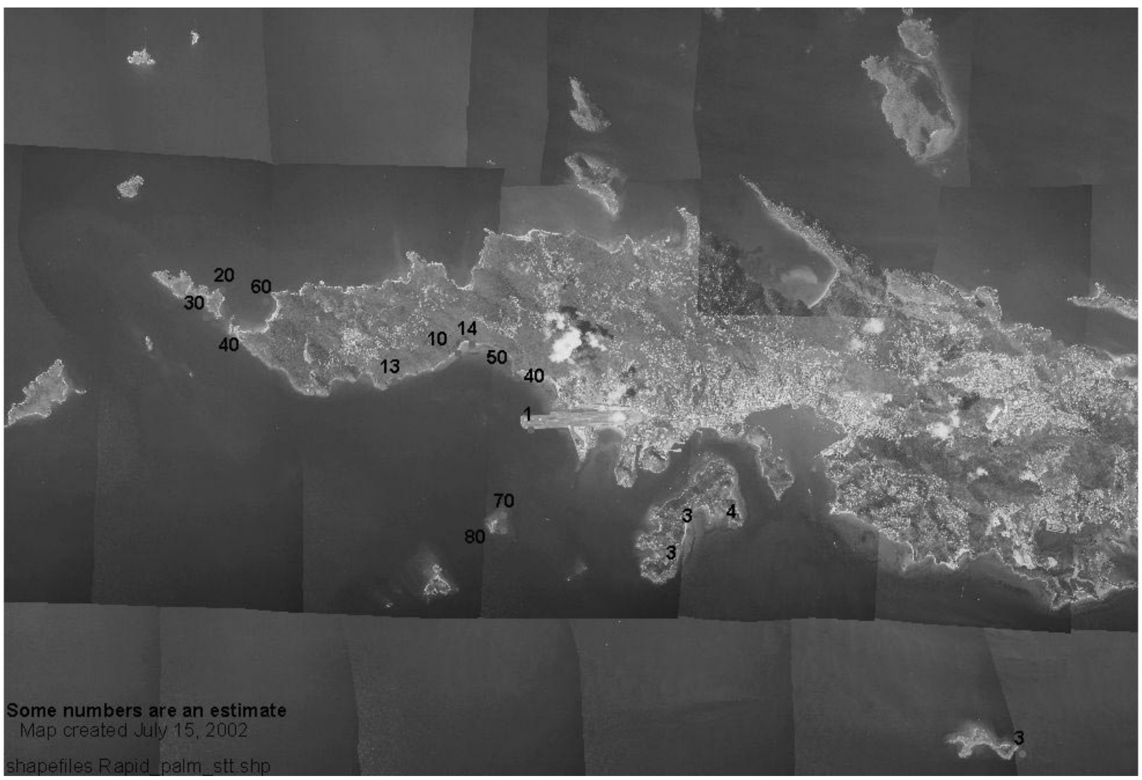
The existence of large *A. palmata* "ghosts" and fragments of *A. cervicornis* indicate that at one time these species were the main reef-building corals in the near shore areas of St. Thomas and outlying cays. These corals apparently succumbed to white-band disease and hurricanes. Live stands of *A. palmata* as well as dead, upright colonies can be found just south east of Buck Island (St. Thomas); east of Flat Cay, Hull Bay, Botany Bay; southeast and southwest of West Cay; northeast of the point of Little St. Thomas; and south-east and west of Black Point, Perseverance Bay and David Point (Fig. 13). There are smaller dead colonies of elkhorn as well as live individual colonies in the deeper waters (12 m) of the spur and groove reefs in Sprat Bay and Limestone Bay off Water Island.

It has been reported that extensive thickets of *Acropora cervicornis* existed near Buck Island at depths up to 17m before Hurricane Marilyn in 1995. This storm apparently destroyed these thickets. In June 2002 only a few staghorn colonies were seen in this area, and they appeared to have white-band disease.

Figure 13. The map shows areas that have been surveyed or have been reported to have *Acropora palmata* around St. Thomas as of July 2002.



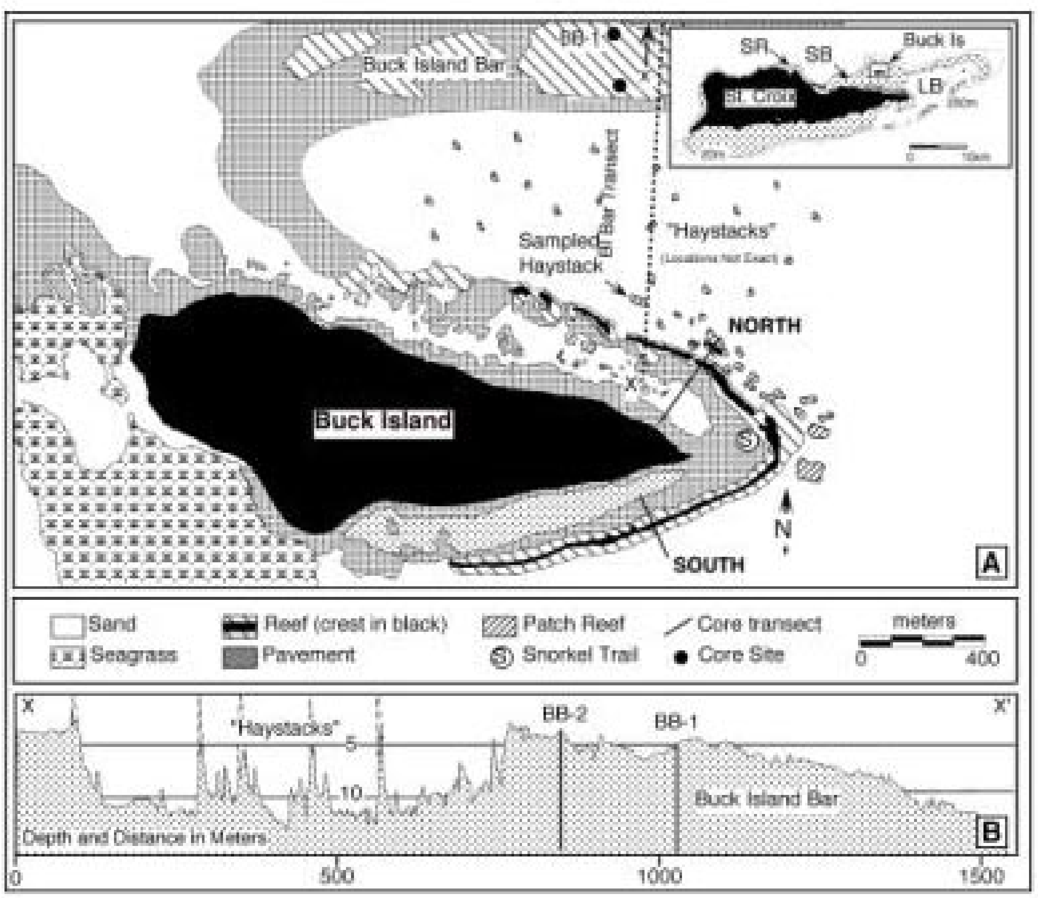
Recent surveys of *Acropora* spp.

Using a rapid assessment method, 448 elkhorn colonies were recorded from 16 locations around St. Thomas (Fig. 13). Of the colonies for which there is information on condition, 63 were healthy, 131 were "moderately" healthy, and 3 were mostly dead. Some of the most extensive elkhorn stands around St. Thomas are found in Botany Bay which is soon to be developed extensively.

LONGER-TERM PATTERNS: A GEOLOGICAL PERSPECTIVE

While the coral reef monitoring and research programs in the USVI, and particularly at Buck Island, provide some of the longest and most complete records of recent *A. palmata* history, they provide only a glimpse of longer-term patterns. Perhaps the greatest question with respect to the recent decline in abundance of this (and other) species is the relative importance of anthropogenic factors versus natural, cyclic change. Jackson (1992) and others have examined Pleistocene reefs and noted a zonation pattern similar to what was seen on Modern reefs prior to the early 1980's. It has been suggested that this fidelity of zonation reflects conditions 125,000 years ago that were more stable than those occurring today. It is tempting to conclude from this that the "more stable" Pleistocene reefs can be used to characterize "pre-anthropogenic conditions" and contrasted with the reef decline of recent decades. However, Jackson (1991) cautioned that apparent stability can change dramatically depending on either temporal or spatial scale. When viewed over longer periods (i.e., time averaging) or across greater distances, reef communities will appear more stable than the "chaos" that often characterizes community dynamics at the quadrat level. Thus, the question remains, "How do we use the recent geologic record as a backdrop for recent losses of *Acropora*?"

Figure 14. Map showing the location of coring transects across the northern and southern portions of Buck Island reef. The location of Buck Island relative to St. Croix is shown in the inset. A profile across Buck Island Bar showing core locations is provided below the map.



A coring investigation was conducted at Buck Island in 1989 and 1990 to document the Holocene development of the reef. Seven cores were taken along two transects that correspond to biological monitoring stations (BI- 3 on the north and BI- 2 to the south:Fig. 14). An additional core was recovered from Buck Island Bar on the exposed platform north of Buck Island.

If one compares the relative percent cover of the main coral species (and total coral abundance) in the cores to monitoring data from the same locations, a striking similarity exists between the time-averaged community structure over the past 7,000 years and the pre-WBD reef community. This is in line with Jackson's observations on Pleistocene reefs and strongly suggests that a reef community dominated by *A. palmata* has been the norm at Buck Island over the past seven millennia.

It is tempting to take these observations further and imply that this spatial persistence reflects temporal stability of the reef community. This similarity has in fact been cited as evidence that "the regional *Acropora* kill is without precedent in the late Holocene" (Aronson and Precht 2001). However, a closer examination of the data from the Buck Island cores and other Caribbean sites indicate that the situation is not this simple.

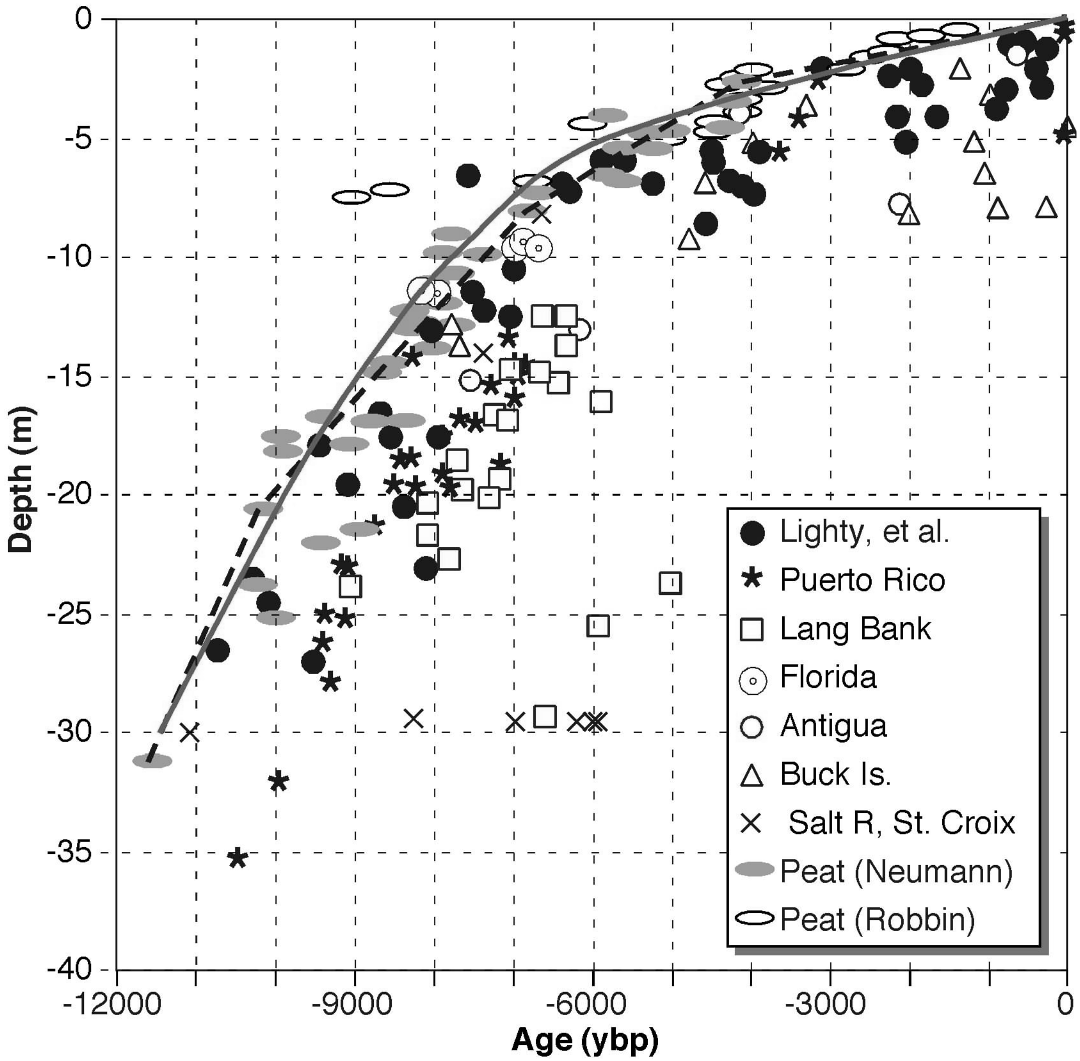
Early development at Buck Island was dominated by massive corals, despite oceanographic conditions seemingly more favorable for *Acropora* growth (i.e., clear, shallow water with active circulation). This pattern is also typical of the Florida Keys and other shallow reefs developing at this time. *Acropora palmata* eventually took over the reef crest but again disappeared from the Buck Island system around 3,000 years ago. It re-established after nearly a thousand year hiatus. If one compares this pattern to the larger Caribbean, it appears that the absence of *A. palmata* from Buck Island is part of a larger, regional pattern.

Figure 15 summarizes the pattern of *A. palmata* occurrence based on over 120 samples (ages are either calibrated $_{14}$C or U/Th determinations). Starting around 6,000 Cal bp ("calibrated years before present"), the abundance of *A. palmata* samples decreases dramatically (note that the flattened circles are mangrove peat dates and not coral dates). This corresponds to the time when Caribbean reefs that one would expect to have been dominated by *A. palmata* were not. Again, *A. palmata* is not seen between 3,000 and 2,000 Cal bp. This corresponds to the shift from *A. palmata* to massive corals at Buck Island.

The widespread occurrence of these gaps across the Caribbean argues for a regional or global cause. Sudden changes in sea level or local oceanographic conditions cannot explain the pattern. The confinement of the event to *A. palmata* and its broad impact are similar to the recent white-band disease outbreak. While an absolute link cannot be proven at this time, the occurrence of widespread *A. palmata* losses twice in the recent geologic past argue against such events being "unprecedented".

Whatever the cause for past outbreaks, anthropogenic factors have played an important role in recent reef decline and rising human exploitation of tropical coastal areas cannot continue without serious negative repercussions. The above discussion argues for a re-examination of our newfound confidence in separating natural from anthropogenic change. The geologic past provides an important long-term record against which present-day change can be considered. However, until we address spatial and temporal scaling problems inherent in comparing a time-averaged record created over thousands of years to monitoring records spanning at best three decades, accurately applying the ancient record will remain an elusive goal. In the balance lies our ability to make objective and scientifically grounded management decisions on a local, regional or global scale.

Figure 15. Plot of age and depth (relative to present sea level) of Caribbean *A. palmata* samples. The sealevel curves of Lighty et al (1981: solid) and Neumann (unpubl.) are also shown. Note the gaps in *A. palmata* starting at ca. 6,000 and 3,000 Cal bp. From Hubbard et al (2000, in press).



CONCLUSIONS

• None of the reefs that has recently been surveyed has a density or percent cover of elkhorn coral equivalent to what it had in the past. Overall tissue reduction in the reef zones formally dominated by *Acropora palmata* has been catastrophic, two orders of magnitude or greater. "Graveyards" of elkhorn, where detached dead branches of this species are interspersed among dead but standing colonies, are still visible on many reefs. However, at least at some locations around all three of the major islands, St. Thomas, St. Croix, and St. John, there is evidence that elkhorn coral is recovering. Maximum cover of elkhorn noted to date around St. John was 30% for a small area on Hawksnest Reef and 3.6% at Romney Reef off St. Croix.

• Staghorn coral is now relatively rare around St. Croix but numerous, mostly isolated colonies are common around St. John.

• Comparisons of previous and present values for percent cover will usually underestimate the actual declines in elkhorn because of the coral's complex morphology. This is because the present colonies are small, and many are primarily crusts, rather than complex three-dimensional colonies as in the past. Those colonies stood several meters above the substrate with live tissue covering not only the top and bottom of the branches, but extending down to the base of the colony as well.

• White-band disease has been more responsible for mortality of the *Acropora* spp. than any other factor in the USVI, although the physical damage from hurricanes has jeopardized recovery from this disease. No active WBD has been noted on elkhorn corals around St. John this year, and it was seen on only a few colonies around St. Croix. Staghorn corals often have freshly killed portions for which the cause is unknown. WBD appears to be responsible in some cases.

• Sexual recruitment of *A. palmata* has been successful at many locations.

• Although the *Acropora* spp. can reproduce effectively through fragmentation (Highsmith 1982), the storm-generated fragments of these species in the USVI have not survived and grown to replace the reefs decimated by disease and storms.

• Many of the new coral colonies are in very shallow water close to shore making them especially vulnerable to runoff from development, exposure at low tide, and storm surge. Many are exhibiting considerable losses to snail predation. It is not clear if recovery will continue.

• Although elkhorn coral has many mechanisms for recovering from physical damage, and fragments can develop into new colonies, it is not clear that it will be as successful at recovering from the current assault from the overall, unprecedented combination of stresses (including predation and disease).

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